

Vertical distribution of chromium in the atmospheres of HgMn stars *

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Abstract. We use multiplet 30 Cr II lines in the wings of H_{β} to test the hypothesis of an anomalous concentration of Cr in the upper layers of the atmospheres of a sample of 10 HgMn stars. These lines are at different distances from the H_{β} line center and are therefore formed at different depths in the stellar atmosphere. Except for HD 49606, all HgMn stars show an increase of Cr abundance with height in the stellar atmosphere. A similar vertical distribution of Cr, but less pronounced, has been previously found in Am stars. In contrast, no variation of Cr abundance with the depth has been found for the normal late B-type star HD 196426 and the weak magnetic late B-type star HD 168733. It is possible that in HgMn stars the vertical stratification parameter, a , depends on T_{eff} , with the strongest vertical gradient being found in the hotter stars. No correlation was found between a and the average stellar abundance $\log \epsilon(\text{Cr}/\text{H})$.

Key words. stars: abundances – stars: atmospheres – stars: chemically peculiar – stars

1. Introduction

The HgMn stars belong to spectral types between A0 and B7 and show marked peculiarities in atmospheric abundances. The most distinctive features of their atmospheres are extreme overabundances of Hg (sometimes exceeding 5 dex) and/or Mn (up to 3 dex). The HgMn stars are slow rotators (Abt et al. 1972) and appear not to have strong large-scale organized magnetic fields such as those of other chemically peculiar (CP) stars of similar temperature, the Si and He-weak stars. This does not definitely rule out the presence of more complex fields of kilogauss order, as suggested by Hubrig and collaborators (Hubrig & Castelli 2001 and references therein).

To explain the abundance anomalies in the outer layers of HgMn stars, radiatively driven selective diffusion in relatively quiescent atmospheres is most often invoked. The HgMn stars are too hot to have a superficial hydrogen convection zone, and, due to gravitational settling of He they are expected not to have He^+ convective zones.

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Therefore, diffusion occurs in the absence of mixing due to convection and of stronger meridional circulations that will occur in faster rotators.

In contrast to the CP stars with large-scale organized magnetic fields, the HgMn stars generally do not exhibit periodic variations in photometry and spectral line intensities. The interpretation of variability of magnetic CP stars is that the surface properties (e.g. abundance distribution of certain elements, distribution of the magnetic field) are non-uniform and non-symmetric with respect to their rotation axis. On the basis of indirect arguments, Hubrig & Mathys (1995) had suggested that at least two chemical elements (Hg and Mn) might be inhomogeneously distributed over the surface of HgMn stars. Very recently, for the moderately rotating HgMn star α And periodic line profile changes in the Hg II $\lambda 3984$ have been reported by Wahlgren et al. (2001) and Adelman et al. (2002), who could show that the reason for the variability is the non-symmetrical distribution of Hg over the surface of α And.

Aside from surface inhomogeneities in the atmospheres of CP stars, an observational evidence is accumulating in the last years that a number of observed spectroscopic features cannot be reproduced with the standard model atmosphere codes in which vertical abundance variations are

neglected and where a homogeneous photospheric abundance is assumed (e.g. Ryabchikova et al. 2002). Most observational studies of the abundance stratification have been devoted to magnetic CP stars and rapidly oscillating Ap stars (e.g. Ryabchikova et al. 2003), for which the impact of the abundance stratification could be significant and for which it has to be taken into account in modelling of pulsational radial velocities, magnetic fields and for abundance determination.

A direct method of determining the vertical stratification is by a comparative analysis of spectral lines which are formed at different depths. Abundances from lines of the same ions formed on either side of the Balmer jump, in the UV and visual spectral regions (e.g., Alecian 1982; Lanz et al. 1993), or from the Cr II lines of mult. 30 in the wings of H_{β} (Savanov et al. 2001a), have been determined in a small number of CP stars. The method of abundance analysis using eight Cr II lines of the same multiplet in the wings of the H_{β} line was introduced by Khokhlova & Topil'skaya (1992). This presents an excellent opportunity to investigate the vertical stratification in normal and chemically peculiar stars of spectral types from B to F. The Cr II lines have well-determined relative oscillator strengths and cover a fairly wide wavelength range in the wings of the H_{β} line, being situated at distances $\Delta\lambda$ of 1.1 Å to 49.0 Å from the line center. If stratification of Cr is indeed present, and if this element is overabundant in a thin surface layer, then the dependence of the spectral line intensities on $\Delta\lambda$ will be markedly different from that in a homogeneous atmosphere. A review of the methods of studying vertical stratification in the stellar atmospheres is given in Savanov & Kochukhov (1998).

Usually, the abundance anomalies are ascribed to hydrodynamical processes in the outer stellar layers – radiatively-driven diffusion, aided or mitigated by magnetic fields, weak (possibly anisotropic) stellar winds, turbulence, and rotational mixing. However, it is difficult to determine the mechanisms responsible for abundance anomalies in the absence of accurate observational information about elemental abundances. The vertical stratification of Cr has not yet been studied for a representative number of HgMn stars. Savanov et al. (2001a) studied Cr II lines of mult. 30 in the wings of the H_{β} line in a sample of magnetic CP stars, Am stars and one HgMn star (46 Dra). We present in this paper our results of the analysis of abundance stratification in ten slowly rotating HgMn stars. One weak magnetic late B-type star, HD 168733, and one normal late B-type star, HD 196426, have been observed as comparison stars.

2. Observations and data reduction

Spectra of seven HgMn stars in our sample, HD 33904, HD 49606, HD 71066, HD 78316, HD 110073, HD 124740 and HD 165493, were observed on March 14, 1999 at ESO with the New Technology Telescope (NTT) and the ESO Multi Mode Instrument (EMMI). The red arm of EMMI was used in the cross-dispersed echelle mode. The main

Table 1. Model atmosphere parameters of the studied stars

Star	T_{eff}	$\log g$	$V \sin i$	Reference
				km s^{-1}
HD 1909 ^a	12400	4.00	13.0	Adelman et al. 1996
HD 33904	12500	3.62	15.0	Adelman et al. 1996
HD 49606	14375	3.90	15.0	Adelman et al. 1996
HD 71066	12100	3.95	2.0	Hubrig et al. 1999
HD 78316 ^b	13250	3.75	6.0	Adelman & Pintado 2000
HD 110073	12900	3.75	1.8	Woolf, Lambert 1999
HD 124740 ^c	10350	4.00	2.0	Dolk et al. 2003
HD 165493	13890	3.90	2.8	Hubrig et al. 1999
HD 168733	13500	3.30	10.0	Lanz et al. 1993
HD 175640	12000	3.95	2.5	Hubrig et al. 1999
HD 178065	12200	3.54	1.5	Hubrig et al. 1999
HD 196426	12815	3.89	3.0	Hubrig et al. 1999

^a For HD 1909B : $T_{\text{eff}}=9000$ K, $\log g=4.0$, $V \sin i = 12 \text{ km s}^{-1}$ (Wahlgren et al. 2002)

^b For HD 78316B : $T_{\text{eff}}=8000$ K, $\log g=4.0$, $V \sin i = 40 \text{ km s}^{-1}$ (Ryabchikova et al. 1998)

^c For HD 124740B : $T_{\text{eff}}=8000$ K, $\log g=4.0$, $V \sin i = 5 \text{ km s}^{-1}$ (Dolk et al. 2003)

dispersing element was the EMMI grating #14, a 31.6 lines/mm echelle grating mounted in the R4 configuration. As cross-disperser, the EMMI grism #5 was employed. The detector was CCD #36, a Tektronix with 2048×2048 pixels of $24 \times 24 \mu\text{m}^2$. Setting the entrance slit of the spectrograph to a width of 0''.8, a resolving power $\lambda/\Delta\lambda \approx 7 \times 10^4$ was achieved over the whole wavelength range (3970–6620 Å).

The data reduction was performed using the ESO image processing package MIDAS. Echelle orders were automatically detected by a Hough transform, and a two-dimensional polynomial fit was computed to define their location on the CCD. For both the scientific and the flat field frames, the background scattered light was modelled by fitting its level in the interorders by a 2-dimensional cubic spline. The result was subtracted from the corresponding exposure, prior to the division of the scientific frame by the flat field. The echelle orders were then extracted from the resulting frames.

Spectra of the three HgMn stars HD 1909, HD 175640 and HD 178065, have been recorded on June 13, 2001 at ESO with the VLT UV-Visual Echelle Spectrograph UVES at UT2. We used the UVES Dichroic standard settings covering the spectral range from 3030 Å to 10000 Å. The slit width was set to 0''.3, corresponding to a resolving power of $\lambda/\Delta\lambda \approx 1.1 \times 10^5$. One weak magnetic late B-type star, HD 168733, and one normal late B-type star, HD 196426, have been observed with the UVES standard setting RED 580 covering the spectral range from 4800 Å to 6800 Å and the entrance slit of the spectrograph set to 0''.3 on May 28, 2000. The spectra have been reduced

by the UVES pipeline Data Reduction Software (version 1.4.0), which is an evolved version of the ECHELLE context of MIDAS. The signal-to-noise ratios of the resulting NTT and UVES spectra are very high, ranging from 200 to 500 per pixel in the one-dimensional spectrum.

3. Spectrum synthesis calculations

Model atmosphere parameters for the studied HgMn stars have already been determined in the past by us and other authors. In Table 1, for each star, cols. 2–4 list effective temperature, surface gravity and the $v \sin i$ values. The last column gives references to the papers in which the model atmosphere parameters have been determined. Three stars in our sample, HD 1909, HD 78316 and HD 124740, are known to be spectroscopic binaries. The adopted parameters of the companions are presented in the footnotes of Table 1. Model atmospheres were taken from the Kurucz model grid `ap00k2odfnew` (Kurucz 2000).

The spectra were analysed using the spectral synthesis code `STARSP` (Tsymbal 1996). The details concerning the calculation of synthetical spectra, broadening due to the instrumental profile and stellar rotation, and fitting to the observations can be found in the paper of Savanov et al. (2001a). The Vienna Atomic Line Database `VALD` (Piskunov et al. 1995) was used as a primary source of the oscillator strengths and other spectral line parameters. The synthetic spectra of three HgMn stars which are known to be spectroscopic binaries, HD 1909, HD 78316 and HD 124740, were calculated and combined using the `BINARY` routine in `STARSP`, or with an IDL routine based on general relations for composite spectra in binary stars which can be found in Savanov et al. (2001a).

Adelman (1994) showed that most HgMn stars have little or no turbulence. Therefore, in all calculations we assumed zero microturbulent velocity. The $v \sin i$ values have been taken either from the referred papers or they were estimated independently from the comparison of the observed and computed spectra, after having degraded the computed spectra for instrumental broadening. An abundance analysis of Cr II was made by matching the observed line profiles and computed synthetic spectra. As all eight Cr II lines of the mult. 30 lie in the wings of the hydrogen H_β line, particular attention has been paid to drawing the continuum. The adopted continuum completely relied on the synthetic H_β profiles, so that the continuum level for the observed spectra was fixed by the computed synthetic spectra in which the wings of the H_β line profile were regarded as local continuum. To check the correctness of our results, the synthetic spectra have also been calculated with two other different codes, `SYNT` (Piskunov 1992) and `SPECTRUM` (Gray <http://www1.appstate.edu/>). The results of the Cr II abundances are in good agreement between all three codes. The difference in synthetic hydrogen line profiles calculated by these codes becomes noticeable only in the central part ($\pm 2 \text{ \AA}$ from the center of H_β). However, this part of the line profile is not used in our abundance analysis.

In the previous analyses of β CrB by Savanov & Kochukhov (1998) and of 17 Com by Savanov et al. (2001a) the authors studied the dependence of the accuracy of the Cr abundance determination on the changes in the stellar parameters and metallicity by running multiple syntheses. They could show that the small changes in local continuum due to errors in atmospheric parameters or incorporating of additional broadening of the H_β profile do not produce any significant effect on the determinations of parameters characterizing the Cr vertical stratification. The atomic data for the synthesis of Cr II lines of the 30th multiplet used in these previous studies were taken from the `VALD` database. The theoretical gf-values given by Kurucz and Bell (1995) supported the relative scale of oscillator strengths. In addition, the calculations for the standard stars with no stratification of Cr in their atmospheres have been regarded as a check for reliability of the procedure of the analysis and of the gf-values.

To estimate the uncertainties in the resulting values of $\log \varepsilon(\text{Cr/H})$ and the accuracy of the fitting of the observed spectrum by the synthetic spectrum, a grid of synthetical spectra has been calculated for each star assuming a change of ± 0.30 dex in the Cr abundance. The values of $\log \varepsilon(\text{Cr/H})$ for each Cr II line have been obtained by quadratic interpolation in the grid. As a result, the uncertainty in the fitting procedure introduces an error of about 0.05 dex in $\log \varepsilon(\text{Cr/H})$ for the HgMn stars with the highest Cr abundance. The error is by a factor 1.5–2.0 larger for the hot HgMn stars where the Cr II lines are intrinsically weak or Cr is underabundant. The results for the Cr abundances of the studied stars derived from different Cr II lines of mult. 30 are presented in Table 2. For the two hottest HgMn stars, HD 49606 and HD 165493, a few of the Cr II lines which are the closest to the center of the H_β line are very weak and could not be used for the abundance analysis.

4. Results and discussion

Fig. 1 shows plots of the Cr abundances as a function of distance from H_β line center for all 12 stars of our sample including the components of the HgMn spectroscopic binary 46 Dra from Savanov et al. (2001a). Abundances are shown on a scale where $\log \varepsilon(\text{H})=0.0$. The results of our analysis are summarized in Table 3. In the second column we give the linear regression coefficient a (the average Cr abundance gradient) and its error σ_a found in an approximation of the Cr abundance as a function of $\Delta\lambda$ by the formula $\log \varepsilon(\text{Cr/H}) = a \times \Delta\lambda + b$. The coefficient a is equal to the tangent of the angle of inclination of the dependence of $\log \varepsilon(\text{Cr/H})$ on $\Delta\lambda$ and is a quantitative characteristic of the vertical Cr abundance gradient. Negative values of a correspond to an increase of chromium abundance in upper layers of the stellar atmosphere. The linear regression coefficient, a , and its error, σ_a , have been determined with an IDL routine which uses the subroutine `SVDFIT`. This parameter can be regarded as a first approximation to the vertical distribution of the element in

Table 2. The Cr abundances derived from the individual Cr II lines of mult. 30

λ Å	$\Delta \lambda$ Å	$\log gf$ (VALD)	HD 1909	HD 33904	HD 49606	HD 71066	HD 78316	HD 110073	HD 124740	HD 165493	HD 168733	HD 175640	HD 178065	HD 196426
4812.34	48.98	-1.96	-6.40	-6.00	-6.20	-6.30	-6.30	-5.70	-5.75	-6.90	-5.60	-5.60	-6.05	-6.65
4824.13	37.19	-0.97	-6.40	-5.85	-6.15	-6.10	-6.30	-5.60	-5.50	-6.90	-5.70	-5.55	-5.95	-6.70
4836.23	25.09	-1.96	-6.20	-5.90	-6.20	-6.20	-6.20	-5.65	-5.80	-6.60	-5.50	-5.55	-5.95	-6.70
4848.24	13.08	-1.15	-6.40	-5.80	-6.25	-6.20	-6.10	-5.65	-5.10	-6.60	-5.60	-5.35	-5.85	-6.80
4856.19	5.13	-2.14	-6.00	-5.80		-5.80	-6.00	-5.40	-5.50		-5.50	-5.30	-5.80	-6.60
4864.33	2.98	-1.36	-6.00	-5.70		-5.75	-6.00	-5.40	-5.10	-6.30	-5.70	-5.00	-5.70	-6.60
4876.40	15.08	-1.46	-6.30	-5.80		-6.20	-5.90	-5.60	-5.70	-6.30	-5.65	-5.40	-5.95	-6.75
4884.61	23.29	-2.10	-6.10	-5.90	-6.25	-6.30	-6.00	-5.70	-5.80	-6.90	-5.55	-5.60	-6.00	-6.60

the stellar atmosphere until modeling of concentration of atoms with optical or geometrical depth can be performed (e.g. Savanov et al. 2001b, Ryabchikova et al. 2002). The last column of Table 3 shows the 'mean' values of the Cr abundances which were determined from the $\log \varepsilon(\text{Cr}/\text{H})$ of the four Cr II lines at distances larger than 20 Å from the center of the H_β line and should be regarded as upper limits for the Cr abundances.

In Table 4 we compare the 'mean' values of the Cr abundance with the results obtained in previous studies. The agreement between our abundances and the abundances given in the literature is rather good, although some discrepancies exist for the stars HD 1909, HD 49606 and HD 78316. The binary nature of HD 1909 has been recognized by Wahlgren et al. (2002). However, the star has been considered as a single star in the studies of Guthrie (1984) and Adelman et al. (1996) who give lower values of Cr abundance compared to our determination. For HD 49606, Adelman et al. (1996) determined a higher Cr abundance (-5.89). On the other hand, our abundance value (-6.20) is fully consistent with the determination of Smith & Dworetsky (1993). Taking into account the presence of the spectral companion we have derived $\log \varepsilon(\text{Cr}/\text{H}) = -6.2$ for HD 78316. This abundance value is lower than the abundance obtained by Adelman & Pintado (2000), but higher than that published by Ryabchikova (1998). As an additional test of the accuracy of the determination of the 'mean' abundances we calculated the Cr abundance in the star HD 175640 using eight unblended Cr II lines of mult. 44 in the spectral region 4550–4620 Å. Calculations were performed with the same source of gf-values (VALD database). We obtained the value of $\log \varepsilon(\text{Cr}/\text{H})$ is equal to -5.55 ± 0.10 , very similar to that derived from the Cr II lines in the far wings of the H_β line (-5.58).

The results presented in Fig. 1 and in Table 3 show that except for HD 49606, in all HgMn stars of our sample the Cr abundance in the atmospheres increases slightly with height in the stellar atmosphere. The average Cr abundance gradient a is -0.0076 ± 0.0028 . This corresponds to an abundance increase of approximately 0.34 dex in going from the 4812.34 Å line to the 4864.33 Å line.

Table 3. The average Cr abundance gradient a , its error σ_a and the derived 'mean' Cr abundance

Star	$(a \pm \sigma_a) * 10^3 \ log \varepsilon(\text{Cr}/\text{H})$
HD 1909	-7.5 ± 3.3
HD 33904	-5.0 ± 1.1
HD 49606	$+2.0 \pm 1.4$
HD 71066	-9.3 ± 4.1
HD 78316	-7.8 ± 2.3
HD 110073	-5.6 ± 2.2
HD 124740	-6.2 ± 1.6
HD 165493	-14.2 ± 4.5
HD 168733	-0.3 ± 2.1
HD 175640	-10.5 ± 3.1
HD 178065	-6.2 ± 1.6
HD 196426	$+0.4 \pm 1.9$
46 Dra A ^a	-5.4 ± 1.3
46 Dra B ^a	-6.4 ± 2.5

^a Data from Savanov et al. 2001a.

Table 4. Cr abundance determinations in the present study and from the literature

Star	$\log \varepsilon$ (Cr/H) <i>this paper</i>	$\log \varepsilon$ (Cr/H)	references
HD 1909	-6.28	-6.40	Guthrie 1984
		-6.68	Adelman et al. 1996
HD 33904	-5.91	-5.89	Adelman & Pintado 2000
HD 49606	-6.20	-5.89	Adelman et al. 1996
		-6.20	Smith & Dworetsky 1993
HD 78316	-6.20	-5.89	Adelman & Pintado 2000
		-6.42	Ryabchikova 1998
HD 110073	-5.66	-5.50	Adelman & Pintado 2000
HD 175640	-5.58	-5.50	Smith & Dworetsky 1993
HD 178065	-5.99	-5.9	Guthrie 1984
		-5.84	Pintado & Adelman 1996
		-5.8	Zakharova 1994
HD 196426	-6.66	-6.60	Smith & Dworetsky 1993

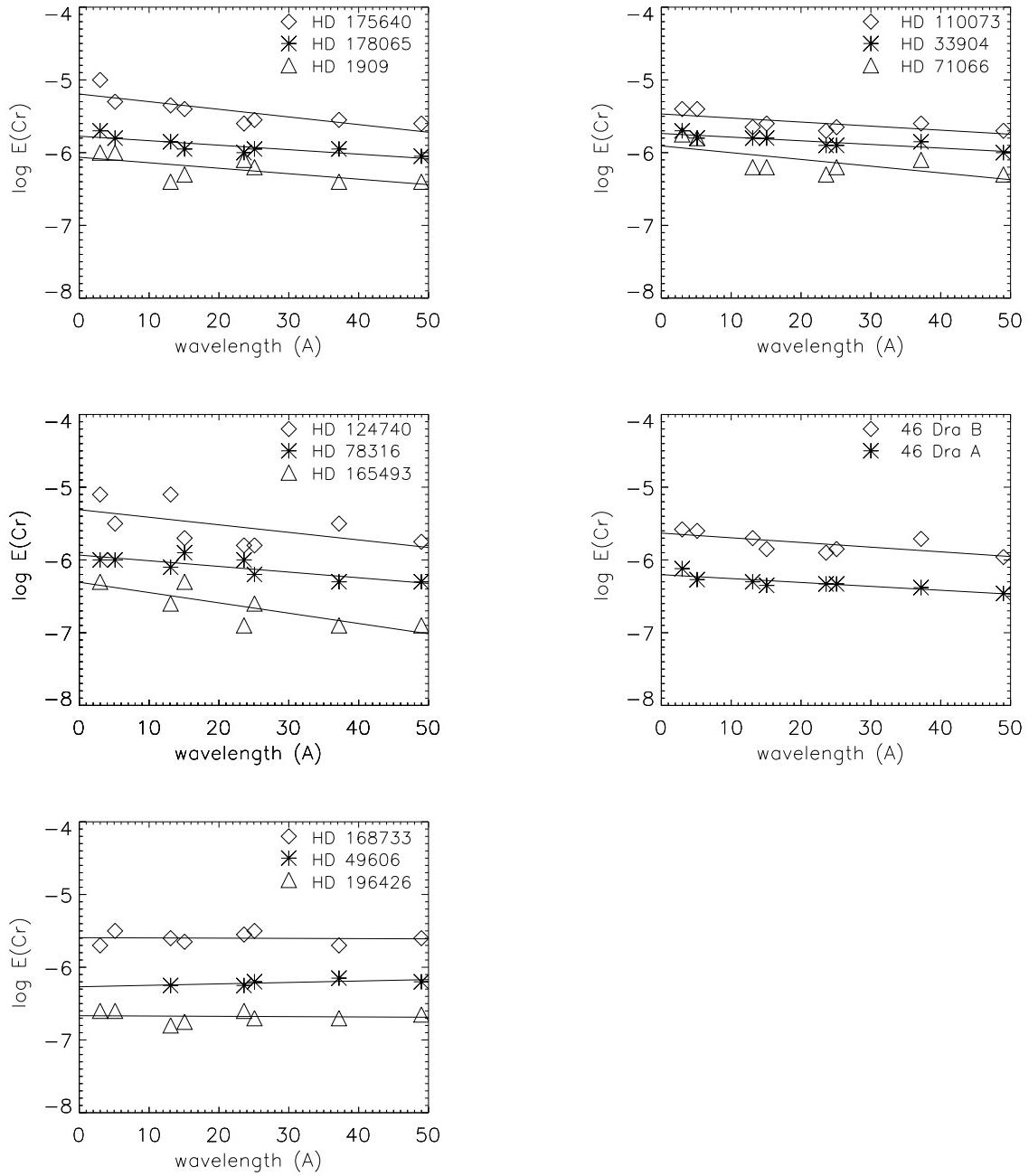


Fig. 1. Linear approximation of the dependence of the Cr abundance on the distance from the center of the H_{β} line.

We found no vertical Cr stratification in the atmosphere of the HgMn star HD 49606, which is the hottest HgMn star in our sample. The model atmosphere parameters for this star have been taken from Adelman et al. (1996). It has been shown by Smith & Dworetsky (1993) that the Cr II lines in the hottest HgMn stars are intrinsically weak. We are not able to measure the chromium abundances from the Cr II lines at 4856.19, 4864.33 and 4876.40 \AA , which are the closest to the center of the H_{β} line. However, other lines of mult. 30 indicate a constant Cr abundance with $\log \varepsilon(\text{Cr}/\text{H}) = -6.20$ (Fig. 1). The star

HD 49606 is of special interest because of the observation of a strong longitudinal magnetic field (1.4 ± 0.2 kG) reported by Glagolevskij, Panov, & Chunakova (1985). However, Hubrig & Launhardt (1993) could not confirm the existence of such a field. The inspection of old photographic spectra revealed splitting of several lines into two components probably caused by a companion. The line profiles on our NTT spectrum show the tendency to be 'square' or rectangular suggesting incipient separation into two components. Further observations at high resolu-

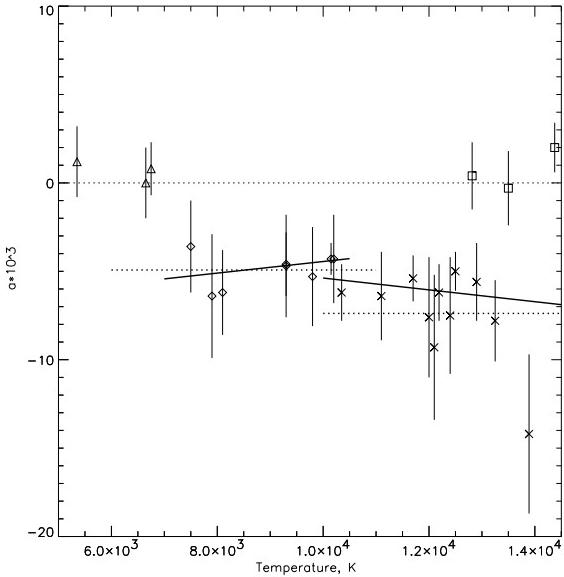


Fig. 2. Dependence of the stratification parameter a on T_{eff} . The three points (triangles) in the 'cool' end of the diagram are for the standard stars Procyon and ι Peg A and B. Diamonds denote results for Am stars and crosses are results from the current investigation of HgMn stars. The three open squares correspond to the stars for which no vertical stratification of the Cr abundance has been found. Dotted lines are mean values for the Am and HgMn groups, while two solid lines are the regressions for each groups.

tion and high S/N are needed to decide definitely whether HD 49606 is indeed a spectroscopic binary.

No variations of the Cr abundance with depth have been found for the normal late B-type star HD 196426 and the magnetic star HD 168733. The longitudinal magnetic field of HD 168733 is rather weak, about -600 G, and not detectably variable (Mathys & Hubrig 1997). The lack of stratification of Cr in the magnetic star HD 168733 is consistent with the results of the previous analyses of the stars 17 Com and α^2 CVn (Savanov et al. 2001a). In contrast, an increase of the Cr abundance with depth was found for the cool magnetic stars β CrB, γ Equ and 10 Aql (Savanov & Kochukhov 1998; Savanov et al. 2001a). The result for γ Equ has been confirmed in the later study by Ryabchikova et al. (2002) who presented also an evidence for abundance stratification of other elements (Ca, Fe, Ba, Si, Na, Pr and Nd).

To search for possible general relations, we studied the dependence between the vertical stratification parameter a and T_{eff} , and between a and the Cr abundance $\log \varepsilon(\text{Cr}/\text{H})$ (Fig. 2, 3). In previous studies Procyon and ι Peg A, B have been used as standards with normal atmospheres and known abundances. As ι Peg is a spectroscopic binary, spectra of the components were calculated and combined using the BINARY subprogram. As expected, no stratification of Cr was found in their atmo-

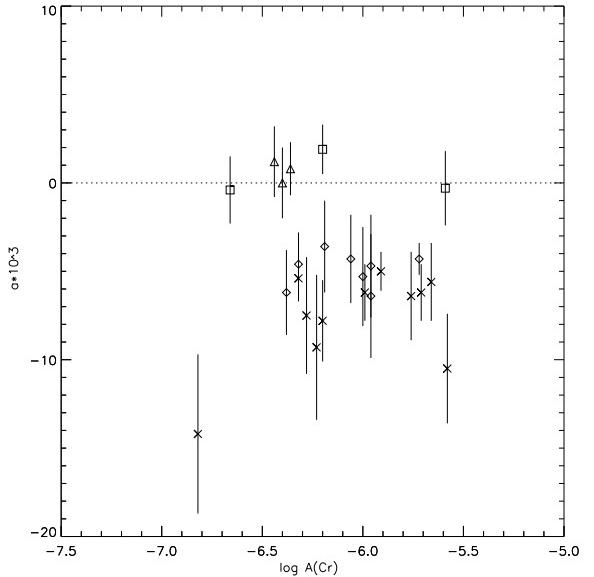


Fig. 3. Stratification parameter a as a function of the Cr abundance. Symbols are the same as on Fig. 2.

spheres (Savanov & Kochukhov, 1998 and Savanov et al. 2001a). These stars are presented by the three triangles in the 'cool' end of Fig. 2. The diamonds show the results for Am stars which occupy the temperature region from about 7500 K to 10000 K. The crosses display the results for the HgMn stars, whereas three open squares correspond to the stars for which no vertical stratification of Cr has been found (HD 49606, HD 196426 and HD 168733).

There is no significant difference in a between Am and HgMn stars in the temperature region of about 10 000 K. From Fig. 2 we may conclude that both groups, Am and HgMn stars, show an increase of the Cr abundance in the upper atmospheric layers. This effect is more pronounced in stars of the HgMn group, for which a mean value of $a = (-7.38 \pm 0.78) \times 10^{-3}$ was obtained. For Am stars we find $a = (-4.93 \pm 0.34) \times 10^{-3}$. The mean values for both groups are shown in Fig. 2 by dotted lines. Two solid lines show the regressions for stars of each group. It is quite possible that the vertical stratification parameter a depends on T_{eff} in HgMn stars. To confirm this trend, more observations of HgMn stars on the hotter end are needed.

In Fig. 3 we plot a as a function of $\log \varepsilon(\text{Cr}/\text{H})$. It appears that the amount of Cr stratification ($a \approx -7 \times 10^{-3}$) does not depend on the average abundance, $\log \varepsilon(\text{Cr}/\text{H})$. One star, HD 165493, deviates strongly from this general relation. It is interesting that this hot star shows the lowest Cr abundance in the far wings of the H_{β} line and the strongest vertical Cr abundance gradient $(14.2 \pm 4.5) \times 10^{-3}$. As has been shown by Smith & Dworetsky (1993) the majority of HgMn stars with the $T_{\text{eff}} > 13000$ K exhibit deficiency of Cr. The most remarkable example is the star HD 186122 which is the most Cr deficient star known. HD 186122 has been observed with

UVES in May 2000, but the extreme faintness of the Cr II lines did not allow to carry out the study of Cr abundances in the wings of the H_{β} line. It is possible that the radiative acceleration on Cr II in hotter stars is sufficient to drive it out of the atmosphere. Recently, LTE and NLTE radiative accelerations have been calculated for different elements including iron-peak elements for a stellar model of 12000 K by Hui-Bon-Hoa et al. (2002). They find that the abundances of the iron-peak elements that can be supported by radiation in the atmosphere are consistent with the average abundances of HgMn stars estimated from abundance analyses of individual stars. Additional radiative force calculations would be useful to clarify the origin of the underabundance of Cr in the the hotter ($T_{\text{eff}} \geq 13000$ K) HgMn stars.

5. Conclusions

In comparison to previous studies, our data have been acquired at much higher spectral resolution ($R \geq 70000$) and higher signal-to-noise ratio ($S/N \geq 200$). Such high quality data allowed us to perform an accurate study even for hotter examples of HgMn stars in which the Cr II lines are intrinsically weak. The results of our analysis have been compared with the previous work on Am stars and magnetic CP stars.

We found indications that there is a vertical chromium distribution in the atmospheres of nine HgMn stars. Since our sample of HgMn stars includes stars in a broad range of effective temperatures with different values of surface gravities and different Cr abundance, we took advantage of this fact to search for possible correlations between the parameters describing the vertical stratification and other stellar parameters. The amount of Cr stratification in HgMn stars is similar to that in Am stars. Both groups, Am and HgMn stars, show an increase of chromium abundance in the upper layers of the atmosphere, but this effect is more pronounced for the stars of the HgMn group. This fact seems to support the hypothesis of a possible relationship between these two types of CP stars. On the other hand, the stars of these groups have in some respects very different properties. E.g. microturbulence is high in Am stars, while it is essentially zero in the HgMn stars (Landstreet 1998). Further studies of the Cr abundance in both types of stars are needed. In particular, it would be very enlightening to analyse in the future studies the Cr abundance in the spectral region before and after the Balmer jump.

As steeper slopes are found in hotter HgMn stars, it is quite possible that the vertical stratification parameter a depends on T_{eff} . However, more observations of HgMn stars on the hotter end are needed to confirm this trend.

We found no vertical Cr stratification in the atmospheres of the normal late B-type star HD 196426, the weak magnetic late B-type star HD 168733 and the hot HgMn star HD 49606. It is likely that the hot HgMn star HD 49606 is a double-lined spectroscopic binary system

and the companion should be taken into account in the abundance analysis.

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References

- Abt, H.A., Chaffee, F.H., & Suffolk., G. 1992, ApJ, 175, 779
- Adelman, S.J. 1994, MNRAS, 266 97
- Adelman, S.J., Philip A.G., & Adelman, C.J. 1996, MNRAS, 282, 953
- Adelman, S.J., & Pintado, O.J. 2000, A&A, 354, 899
- Adelman, S. J., Gulliver, A. F., Kochukhov, O. P., & Ryabchikova, T. 2002, ApJ, 575, 449
- Aleian, G. 1982, A&A, 107, 61
- Dolk, L., Wahlgren, G. M., & Hubrig, H. 2003, A&A, submitted.
- Glagolevskij, J.V., Panov, K., & Chunakova, N.M. 1985, Pisma AJ 11, 749
- Guthrie, B. N. G. 1984, MNRAS, 206, 85
- Hubrig, S., & Launhardt, R. 1993, IAU Coll. No. 138, 350
- Hubrig, S., Castelli, F., & Wahlgren, G. M. 1999, A&A, 346, 139
- Hubrig, S., & Castelli, F. 2001, A&A, 375, 963
- Hubrig, S. & Mathys, G. 1995, Comments on Astrophys., 18, 167
- Hui-Bon-Hoa, A., LeBlanc, F., Hauschild, P.H., & Baron, E. 2002, A&A, 381, 197
- Khokhlova, V.L., & Topil'skaya, G.P. 1992, Pis'ma Astron.Zh., 18, 150
- Kurucz, R.L., 2000, <http://www.cfaku5.harvard.edu>
- Kurucz, R.L., Bell, B., 1995, "Atomic Line List", CD-ROM No. 23, Smithsonian Astroph. Obs. Cambridge, MA
- Landstreet, J.D. 1998 A&A, 338, 1041
- Lanz, T., Artru, M. C., Didelon, P., & Mathys, G. 1993, A&A, 272, 465
- Mathys, G., & Hubrig, S. 1997, A&AS, 124, 475
- Pintado, O. I., & Adelman, S. J. 1996 A&AS, 118, 283
- Piskunov, N. 1992, in Stellar magnetism, ed. Y.V.Glagolevskij, & I.I.Romanyuk (Nauka, St.Peterburg), 92
- Piskunov, N., Kupka, F., Ryabchikova, T.A., et al. 1995, A&AS, 112, 525
- Ryabchikova, T., Kotchoukhov, O., Galazutdinov, G., Musaev, F., & Adelman, S. J. 1998, Contributions Astronomical Observatory Skalnate Pleso, 27, 258
- Ryabchikova, T. 1998, Contributions Astronomical Observatory Skalnate Pleso, 27, 319
- Ryabchikova, T., Piskunov, N., Kochukhov, O., Tsymbal, V., Mittermayer, P., & Weiss, W. W. 2002, A&A, 384, 545
- Ryabchikova, T., G.A. Wade, G.A., LeBlanc, F. 2003, A&A, in press
- Savanov, I., & Kochukhov, O. 1998, Astronomy Letters, 24, 516
- Savanov, I.S., Kochukhov O.P., & Tsymbal V.V. 2001a, Astrophysics, 44, 64
- Savanov,I.S., Kochukhov O.P., & Tsymbal V.V. 2001b, Astrophysics, 44, 206
- Smith, K. C., & Dworetsky, M. M. 1993, A&A, 274, 335
- Tsymbal, V.V. 1996, in Model Atmospheres and Stellar Spectra, ASP Conf.Ser., ed. S.J.Adelman, F.Kupka, & W.W.Weiss (ASP Conf.Ser.) 198

- Woolf, V.M., & Lambert D.L. 1999, ApJ, 521, 414
Wahlgren, G. M., Ilyin, I., & Kochukhov, O., 2001, AAS, 199,
3504
Wahlgren, G. M., Hubrig, S., & Dolk, L. 2002, IBVS, 5290, 1
Zakharova, L. A. 1994, AZh, 38, 520